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Advanced Technology Program's Approach to Technology Diffusion

Paper presented at
Advanced Research Workshop
"Industry as a Stimulator of
Technology Transfer"

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ATP's Approach to Technology Diffusion

Paper presented at the NATO Science for Peace Programme Advanced Research Workshop *Industry as a Stimulator of Technology Transfer*

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September 1999

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Preface

The expected joining of NATO by Central and Eastern European countries has heightened interest in the renewal of their national innovation systems as essential to the successful transition to market-based economies. Technology transfer – defined as the ability to integrate artifacts, knowledge and skills from an originating source, adapt them to a different environment, and then diffuse them into new applications – has been identified as an element of crucial importance to the transformation. The Advanced Research Workshop was sponsored under the NATO Science for Peace Program for the purpose of investigating economic and management issues of technology transfer, both on the national and international levels, with a special emphasis on the role of industry in stimulating technology transfer. The Conference assembled approximately 50 experts to address the following specific objectives:

- Identification of the historical background and principal weaknesses in technology transfer in economies in transition countries, considering both locally developed and imported technologies.

- Identification of approaches to technology transfer in advanced technology countries that would be suitable for adoption to the conditions in central and eastern Europe.

- Identification of economic measures and science policy initiatives that have a potential for improving the technology transfer process.

- Identification of technology transfer models with a particularly effective role for industry.

Rosalie Ruegg of the United States' Advanced Technology Program (ATP) was invited to participate because the ATP fosters public-private partnerships in civilian technologies that emphasize both industry leadership and rapid technology diffusion -- both central themes of the Workshop. Keen interest was expressed in the ATP's integrated business/technology planning requirements and in its criteria that encourage collaborative efforts and projects structured to achieve technology development and commercialization goals. ATP's integrated planning requirement and use of project selection criteria are designed to accelerate development of technologies in tune with market forces, early commercialization of products, processes, and services based on the technology platforms developed, and early adoption and diffusion within and across industry sectors.

In addition to contributing to the United States' technology base and the economy, the ATP, through its evaluation program, is contributing to a growing understanding of factors that influence the impact of technological innovation on a nation's economy. It is showing how a public-private partnership program can deliberately accelerate and broaden high-risk technology development and diffusion through cooperative efforts of businesses, universities, and government. The program is of interest not only domestically, but also as a potential model for other nations.

The Advanced Technology Program's Approach to Technology Diffusion

Abstract:

This paper examines the approach to technology diffusion of a public-private partnership program in the United States, the Advanced Technology Program (ATP), that puts industry in the lead and emphasizes spillover effects for national economic benefit. The paper identifies key features of the program by which it promotes technology diffusion, reports on early progress, and discusses challenges faced by the program in achieving intra-industry and inter-industry technology diffusion. The following specific strategies of the ATP for fostering technology diffusion are discussed: (1) selecting "enabling" technologies for funding which by their nature are expected to be particularly conducive to broad use and diffusion; (2) selecting projects with integrated research and business/economic plans, and which are structured organizationally to provide clear pathways to early applications of the technology; (3) encouraging interfirm and other collaborative relationships to strengthen the pathways to rapid development, commercialization and broader diffusion; (4) providing forums to facilitate the diffusion of technology; and (5) evaluating project outcomes, analyzing factors influencing diffusion, and feeding back the results to inform the selection process. Direct and indirect paths of technology diffusion are discussed and illustrated. Alternative structures of project organizations are modeled and their implications for technology diffusion are discussed. Illustrative examples and results are included. The approach of the ATP to technology transfer and its early experience may offer ideas of interest to policy makers in Central and Eastern European countries who seek transformation to a market economy.

Keywords: Advanced Technology Program, collaboration, economic growth, evaluation, NATO, technology policy, technology transfer.

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1. A Public-Private Partnership Program Aimed at Technology Diffusion

The search for new organizational forms that would help fuel progress through innovation in the United States in the twenty-first century has led to a growing interest in public-private partnership programs. Features of special interest are that these programs take advantage of the efficiency of private markets and private firms while oriented towards the public interest. Having industry in the lead keeps the innovative work anchored in the applied world, oriented towards commercial potential, with attention to costs, time, and the bottom line. Having government influence the nature of a subset of the nation's innovative activity allows it to increase national investment in particularly challenging research with large spillovers and high social benefits potential that would tend otherwise to receive lower than optimal investment. The topic of this paper is a U.S. public-private partnership program, the Advanced Technology Program (ATP) that "...harnesses private firms' resources to the public interest without seeking to outguess market forces."[1] Technology transfer is of central importance to the ATP, and its approach to technology transfer and experience thus far may offer ideas suitable for adoption to Central and Eastern European countries in their transformation to a market economy.

The ATP is a relatively recent component among United States strategies to foster innovation in the civilian sector. It is unique in having as its main long-term goal that of economic growth. In contrast, the "U.S. mission agencies," such as the Department of Defense and the Department of Energy, often also call out the importance of the economic effects of research they fund, but their first priority is, respectively, defense and energy. Now reaching its tenth anniversary, the ATP is demonstrating results and believes itself ready for scale-up from its current budgetary level of approximately $200 million annually to major program status. Its mission is to foster the rapid development and commercialization of pre-competitive, generic technologies with potential for significant, diffuse impact on the nation's economy. The program shares part of the research costs with industry of technology development projects conceived, proposed, and led by U.S. companies -- projects that are selected for award by the ATP through a competitive peer-review process that evaluates the technical and business/economic merit of proposals. Each project selected for funding has specific technical and business goals, funding allocations, and completion dates that are established at the outset. The projects are monitored by ATP staff and can be terminated for cause before completion. Funding is on a cost-reimbursable basis. Eligibility extends both to single-company projects, most of which show extensive collaborative activity through subcontracting and informal alliances, and to joint ventures which must include at least two for-profit companies and often include other companies, universities, and non-profit organizations as additional members, as well as subcontracting and informal alliance arrangements. Figure 1 highlights some of the ATP's distinctive features. The summary statistics in figure 2 show through 1998, the cumulative number of proposals received from companies, the amount of money offered by industry and requested from the ATP, the number of

[1] Spender (1997), p. 46.

organizations involved, together with the number of awards made by the ATP, the associated funding, and the number of participating organizations.[2]

Figure 1 - Key Features of the ATP

- Technology development for national economic benefit
- Industry leadership in planning and implementing projects
- Project selection criteria on technical and economic merit
- Annual rigorous competitions based on peer review
- Positioned after basic science and before product development
- Not "entitlement" funding -- all projects have end dates

Figure 2 - Summary Statistics for ATP (1990-1998)

Proposals Received	
Number of proposals	3,585
Total research proposed (U.S. $ millions)	$14,794
Industry share (U.S. $ millions)	$7,103
ATP funding requested (U.S. $ millions)	$7,691
Number of proposing organizations	6,104
Awards Made	
Number of awards	431
Total research funded (U.S. $ millions)	$2,783
Industry share (U.S. $ millions)	$1,997
ATP share (U.S. $ millions)	$1,386
Number of participating organizations	1,010

The ATP has an integrated set of strategies for accomplishing its mission. It funds projects that are desirable for their social benefits, essentially buying down technical risk that exceeds the level acceptable to private investors. It encourages companies, universities, and other organizations to undertake multi-disciplinary collaboration to solve complex problems of broad importance. It focuses on multi-year partnerships needed to address problems that tend to be neglected when short-term perspectives predominate in investment decisions. Through its selection criteria, it fosters the structuring of partnerships that integrate objectives and approaches across the areas of research, commercial interests of the innovator(s), and the national economy. Short of compromising the incentive to commercialize the technology, the ATP encourages companies to share the resulting scientific and technical knowledge with others. In short, the ATP aims to induce industry to undertake challenging research needed to develop enabling technologies with potentially high-payoff potential for the nation, research that businesses otherwise would not undertake at all or not with the scale, scope, or timing needed to realize the potentially large societal benefits. The central importance of technology transfer, or

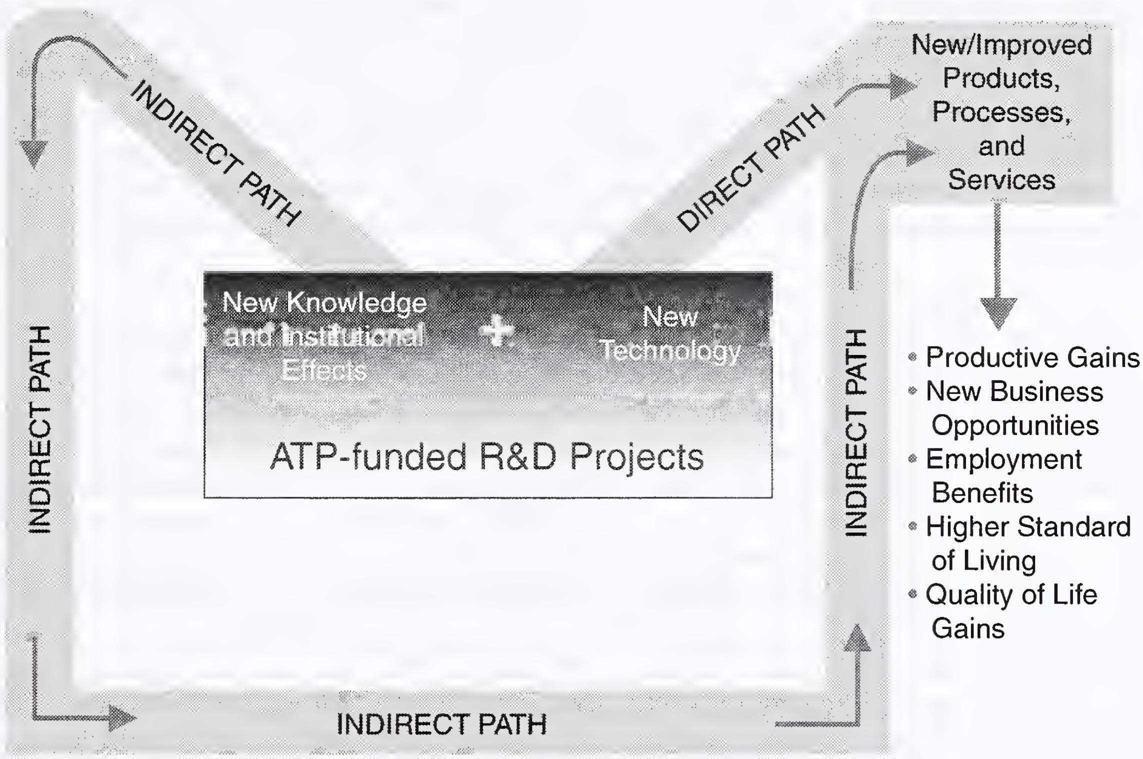
[2] More information about the ATP is available on the World Wide Web: http://www.atp.nist.gov; by e-mail: atp@nist.gov; by phone: 1-800-ATP-FUND (1-800-287-3863); by written request: Advanced Technology Program, National Institute of Standards and Technology, 100 Bureau Drive, Stop 4701, Gaithersburg, MD 20899-4701.

"technology diffusion" as it is often called within the program, is apparent in the ATP's mission, rationale, selection criteria, and operational features.

2. *Direct and Indirect Paths to Technology Diffusion*

As illustrated by figure 3, the ATP's view of technology diffusion encompasses a "direct path" of commercialization through the innovators and their partners in competitive markets, and an "indirect path"of knowledge dissemination leading eventually to commercialization by others.

Figure 3 - Direct and Indirect Paths to Impacts



The direct path yields private benefits capturable by the ATP award recipients in the form of sales revenue, license and royalty fees, and cost savings. The direct path also yields "spillover" benefits (benefits captured by others) in the form of consumer surplus. These tend to be increased as competitors reverse engineer and otherwise copy the ATP-funded enabling technologies and cut into the original innovators' profits.

The indirect path also yields spillover benefits as others obtain knowledge from the project without fully paying for the research, and incorporate that knowledge into other products and services that in turn generate benefits. Knowledge generated in the ATP projects may be diffused to others in a number of ways. Others gain knowledge of a technology through patent disclosures, publications, presentations, discussions among scientists and technologists, and the mobility of scientists and other workers among companies and organizations. Other benefits from use of the technologies that tend not to be fully compensated, such as environmental and other quality of life improvements, may generate additional spillover effects.

Spillover effects, whether from the direct path or the indirect path shown in figure 3, are important to the rationale for the ATP. Economic theory suggests that large spillovers are one reason why private investment in broadly enabling technologies tends to fall below the socially optimal level.[3]

The ATP aims not only to move technology along these direct and indirect paths; it aims to accelerate technology diffusion -- speeding the availability of new, better, or less expensive goods and services, as well as knowledge. Acceleration of the take-up of the technology increases the present value benefits attributable to the ATP's intervention.[4] To this end, the ATP emphasizes early commercialization as an important milestone in achieving technology diffusion. Early commercialization is held to be important because it provides a revenue stream to the innovator which helps keep the businesses viable. It provides a marketplace demonstration of the technology that may hasten other applications. It embodies the knowledge from the project in goods and services that have economic value to consumers, moving it from the realm of knowledge for knowledge's sake, to commercial value. Approximately 100 technologies developed under ATP funding were reported under commercialization as of mid-1999.[5]

It should be noted that commercialization of technologies developed under the ATP occurs in the private marketplace through transactions between firms and between firm and consumer. In this government program -- unlike most of the "mission agencies" such as the U.S. Defense Department and The U.S. Department of Energy -- the government itself is not the principal customer for the goods and services that are eventually derived from the technologies it funds.[6] Neither the ATP, nor its parent organizations, the National Institute of Standards and Technology and the U.S. Department of Commerce, create a market for the resulting goods and services. Rather, the innovating firms must compete with other firms for private sector customers. This feature is both a strength of the program and a source of additional challenge to its administrators. Since the mission of the program is to improve the national economy, and since this will only happen if the technologies, or the resulting knowledge, are eventually applied, the ATP administrators must take added care that the projects selected have feasible pathways from the laboratory into the marketplace.

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[3] For a background discussion of spillover effects, how they are generated, and their implications for technology policy, see Jaffe (1996).

[4] The benefits from accelerating the rate of diffusion along the direct path to commercialization have been estimated for several case studies, see, for example, RTI (1998).

[5] U.S. Department of Commerce Fiscal Year 2000 Annual Performance Plan, 1999, pp. iii-123. The statistics on commercialization are drawn from the ATP's Business Reporting System database.

[6] In some cases the resulting goods and services may have research, military, transportation, or other applications that may lead to significant purchases by government agencies, but these applications are incidental to the envisioned private civilian applications.

3. Technologies with High Potential for Broad-Based Benefits

The technologies funded by the ATP are selected intentionally to have higher-than-average potential to generate spillover effects. This is what is meant by the program's use of the term "enabling technologies." The technologies deemed by the ATP to be enabling have tended to fall into one or more of the following three categories:

(1) *break-through technologies* that promise to revolutionize current practice;
(2) *infrastructural technologies* that underpin entire industry sectors; and
(3) *multi-use technologies* that can be adapted to many different distinct applications requiring specialized knowledge and assets to pursue.

Examples of ATP-funded projects which may help to illustrate each of these three categories of technologies are respectively the following: (1) Human stem cells grown in incubators -- considered at the time the project was selected in the early 1990s to be a breakthrough technology. The results offer the potential of new medical treatments for a variety of conditions. (2) New design and process technologies for printed wiring boards -- which comprise the backbone of electronic devices -- to help the lagging U.S. industry sector leap-frog existing material and process barriers in order to meet twenty-first century needs. Of the more than 700 businesses comprising the U.S. printed wiring board industry, only a few had the capacity to mount a broadly designed, collaborative, advanced research program that would provide new material and process technologies needed by the entire industry sector for international competitiveness. An industry dissemination plan was a component of the project. (3) Dimensional control technologies to increase tightness of fit of assembled parts in discrete manufacturing. Proposed by a team of automotive suppliers, universities, and automobile assemblers, and applied first in the assembly of automobiles, this set of related technologies appears to be adaptable to other discrete manufacturing, such as office furniture and appliances.

Technologies that ATP seeks to avoid funding are: (1) those that are not considered to be inhibited by challenging (risky) technical barriers;[7] (2) those that would represent relatively small incremental changes over existing technologies; (3) those that are expected to have only small, niche-market-applications potential over the long run; (4) those whose development would contribute relatively little to the U.S. scientific and technical knowledge base; (5) those that are actually at the product development stage rather than pre-commercial; (6) those that would be developed in a timely way without the ATP; and (7) those that more appropriately would be funded by a different government agency and/or by private sources of capital. The ATP also seeks to avoid funding technologies under market conditions that will likely inhibit full development, use, and diffusion of the technology, such as where there is a lack of market competition or reasons to believe that a company will "lock up" the new technology rather than exploit it. The ATP aims to stimulate companies to tackle bigger problems and more challenging research than they otherwise would; to leap-frog existing approaches; to develop the technologies of the future.

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[7] The risk embodied in the technology development projects funded by the ATP include high discrete risk, as well as systems integration risk.

4. Integrated Project Planning for Accelerated Technology Adoption and Diffusion

Companies develop their own project plans to propose to the ATP, but the ATP influences that planning through published criteria that it uses to select proposals to fund. The direction of ATP's influence is towards integrated project planning that will foster accelerated routes to market. Although the ATP funds only research -- not product development, it selects proposals on the basis not only of the quality of the research plans, but also on how well the plans recognize market opportunities; on their specific strategies for commercializing the technologies in light of company strengths, weaknesses, resources, and competitive environment; on their commitment to commercialize; on the potential for generating positive spillover effects; and on other business and economic factors that together influence outcomes. Proposals that present only a research plan are rejected. The old sequential planning model of "first we will do the research, then we will identify and plan for potential use" does not fare well against the ATP's selection criteria. As illustrated by figure 4, in place of a sequential planning model, the ATP espouses an integrated, parallel research/business/economics planning model. Embracing the latter model is based on the belief (that is supported by a growing body of evidence) that time and resources will be wasted by developing technologies apart from information about what the market requires.[8]

Award-winning proposals are those framed in the context of a specific problem or opportunity to be addressed, those that include plausible quantitative or qualitative estimates of large expected net benefits that will become broadly distributed, that explain why ATP funding is needed to make it happen and why alternative funding was not available, and that present a plausible pathway to the realization of those benefits.

The requirement for early planning does not mean that the ATP believes that it is possible to know in advance exactly where a new technology will go. Serendipitous applications of technologies happen all the time. Serendipity notwithstanding, the ATP believes that its requirement for early, integrated planning, the associated analysis of markets and opportunities, the development of business contacts, and the focused attention on downstream use and broader diffusion will in two ways improve the odds that commercialization will happen in a timely way:

(1) The strength of the initial planning will indicate to the proposal reviewers the presence or absence of essential business know-how and awareness. (2) If on target, the business plan will bring together the essential pieces for a fast-track approach. These early plans do not become a straightjacket for the companies; appropriate changes can be made throughout a project, as well as in the post-project period. Most projects continue to identify new applications for their technologies, and the companies continue to develop more detailed business plans after the initial plans are developed.[9]

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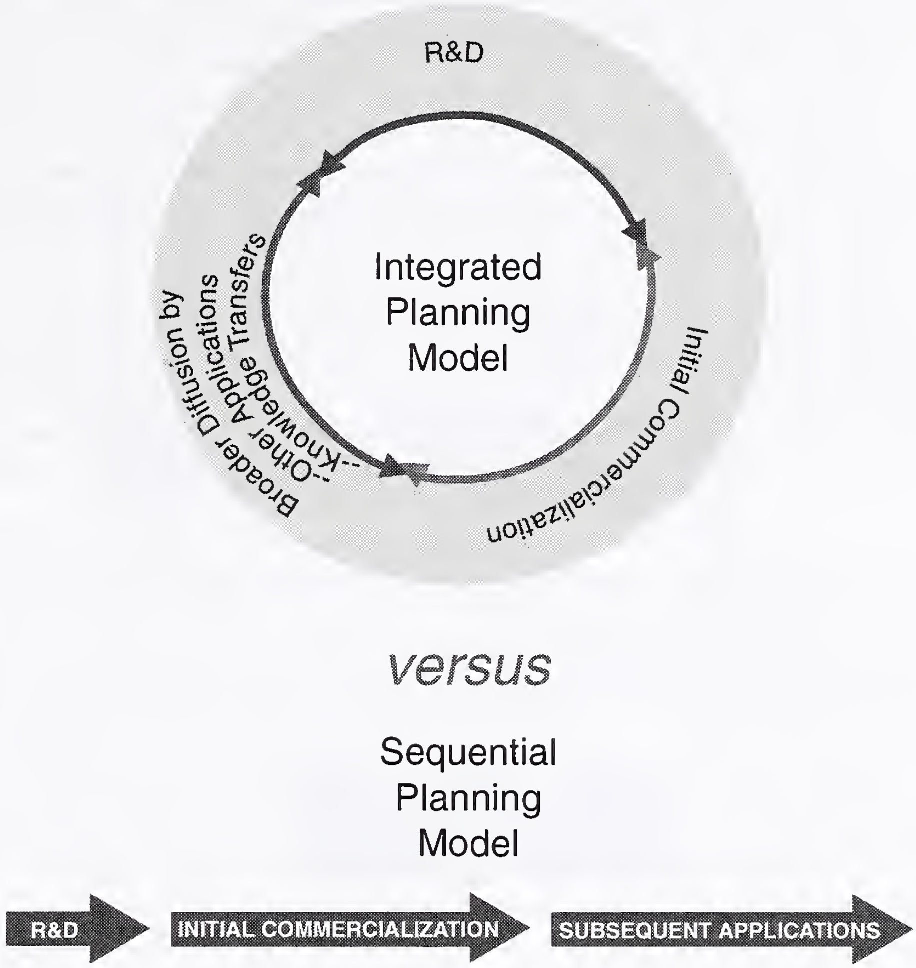
[8] This point that technologies should not be developed in isolation of the market was made emphatically by business leaders and venture capitalists at a recent workshop on making decisions about early stage, high risk research, conducted by Harvard University's John F. Kennedy School of Government and Massachusetts Institute of Technology's Entrepreneurship Center. (Practitioners' Workshop, Cambridge, MA, June 21-22, 1999.)

[9] ATP's Business Reporting System database.

Figure 4 - Integrated, Parallel Planning Model Rather than Sequential Planning Model



5. Projects Structured to Accelerate Technology Adoption and Diffusion

Most of the companies that apply to the ATP are themselves lacking one or more of the essential elements for achieving the goals of their integrated project plans. They must be able not only to perform cutting-edge research, but also to rapidly commercialize and diffuse the resulting goods and services. To strengthen their ability to satisfy the ATP criteria, many proposers seek relationships with other organizations. For example, many of the highly innovative companies are startups, or near startups, that have exciting ideas, but are thin on resources and may altogether lack production capacity and access to broader market distribution channels. While it is generally difficult to see how, acting alone, a small firm can achieve national economic impact, such firms may be able to have large impacts when partnered with other organizations. Many medium-sized companies have only token in-house research laboratories but are an important link in a supply chain. They may need to turn to universities, non-profit research labs, and others for advanced research capabilities, as well as to downstream customers to ensure market acceptance of their new technologies. Many larger companies want to pursue complex systems problems requiring multi-disciplinary approaches or to address industry-wide infrastructural problems that often require collaborators to meet their goals. Non-profit organizations often have promising ideas, but need to team with for-profit companies to meet the commercialization goals. To win an ATP award, deficiencies in the relevant capabilities must be addressed. Formal or informal collaborations are usually the means. The ATP encourages collaborative activities needed to accomplish ambitious project goals.[10]

Some specific illustrations of project structure may increase understanding of the ATP's approach. Figures 5 through 11 illustrate several of the many and varied structures of ATP projects. Each has its own strengths and weaknesses from the perspective of technology diffusion, and may be more or less suited to a particular technology area and market sector. But each structure models a particular technology diffusion plan proposed to the ATP by U.S. businesses. The first group, figures 5 through 8, are all models for single-company awardees that are using informal relationships either to extend their research capabilities or their market reach. The second group, figures 9 through 11, are for joint-venture awardees using formal alliances to help achieve project goals. (Dotted lines indicate informal relationships; solid lines indicate formal relationships. The shaded areas indicate those formally within the ATP partnership.)

Model A in figure 5 is for a small research-oriented, single-company awardee with few resources and no production and distribution capabilities in-house, but highly innovative ideas. Its challenge is to provide a path to economic benefit. In this case, it gives strong evidence of potential customer interest and collaborative support by a large company with extensive production and distribution capabilities. This model fits well the case of the ATP's project with Diamond Semiconductor Group, LLC (DSG), to develop broad-beam ion-implantation technology. A two-person start-up, DSG obtained a commitment from a large manufacturer of ion-implant equipment, Varian Associates, conditional on the ATP award, of assisting with DSG's indirect costs and licensing the technology from DSG if they were successful in the research program. DSG also mapped out a plan, less detailed, for exploring other possible applications of its technology. This arrangement has worked well. DSG developed the ion-implantation technology, for which it received patents. Varian licensed the technology from DSG and was the first company to market equipment that handles large wafer sizes of 300 mm. Chip-fabrication companies purchased the new equipment to make the larger wafers. Purchasers of the larger wafers received cost savings and quality improvements, as did the ultimate consumers of electronic equipment. DSG proceeded to license the technology for other uses.[11]

Model B in figure 6 shows a "balanced" single-company awardee with in-house research, production, marketing, and distribution capabilities which it plans to rely on for its major path to market. This model fits well the case of ATP's award with Molecular Simulations, Inc. (MSI), to develop density functional theory for saving time and costs in the development of new

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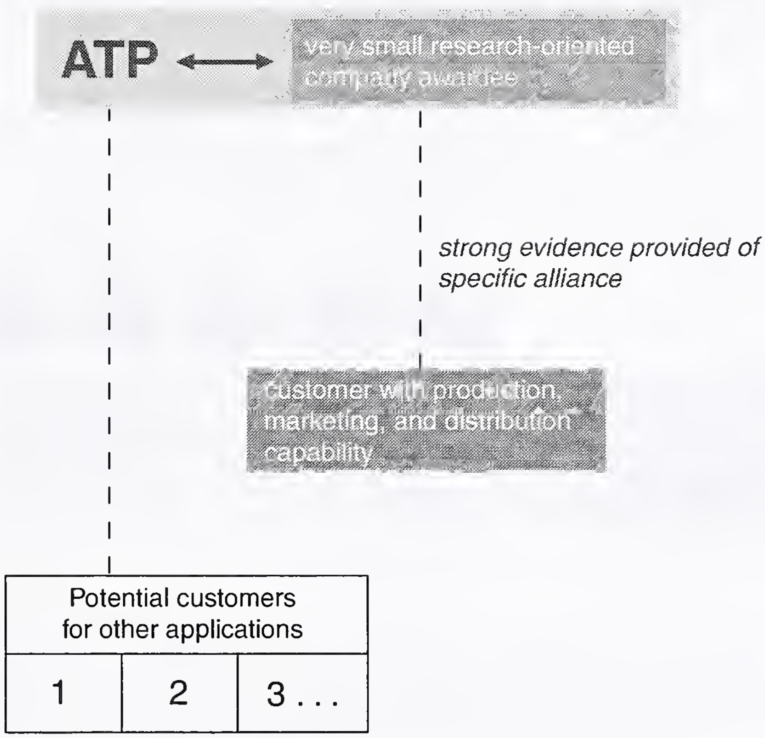
[10] Collaboration is encouraged by the ATP through several legislated provisions: (1) There is no limit on funding available from the ATP to formal joint ventures, while a limit of $2 million applies to projects proposed by single-company applicants. (2) A longer research period is allowed for formal joint ventures than for single-company applicants (5 years versus 3 years maximum). The ATP also hosts numerous workshops to facilitate collaboration, and maintains a website also for that purpose. (Go to ATP's website, http://www.atp.gov, and select "alliance network.")

[11] Long (1999), pp.60-62.

therapeutic drugs and other biochemical substances. Embodied in software, the technology could be feasibly commercialized by a relatively small company with in-house capabilities. MSI's demonstrated track record of being able to develop and market software tools in biochemical markets strengthened its business case. This project has also been successful. Commercialization of the resulting award-winning technology is underway and the software package has been distributed by MSI to more than 100 sites for use by scientists in academic, industrial, and government laboratories for rational drug design and petrochemical research. The technology has other potential applications. More than 30 published papers out of the project added knowledge spillovers to the market spillovers.[12]

Figure 5 - Model A: Small Research-Oriented Company Awardee

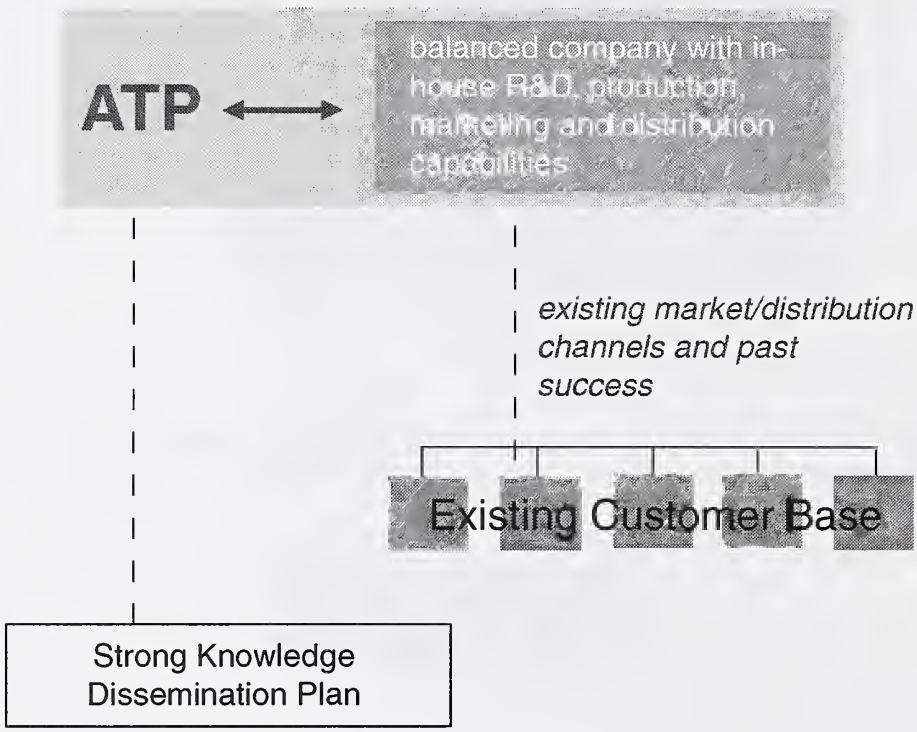


Model C in figure 7 is for a large single-company awardee affiliated upstream with its supplier base for conducting the research. The large company wishes to be the future customer of products from the supplier firms that embody advanced technology which the suppliers acting alone will be unable to provide. If the technology were available and embodied in the suppliers' products, the large company planned to incorporate it into its own product lines for distribution. This case is illustrated by ATP's project with AT&T (Lucent Technologies, Inc.), to work with its supplier base to develop new fabrication, testing and alignment techniques for making extremely precise aspheric mirrors for use in lithography in the extreme ultraviolet (EUV) portion of the spectrum, one of the several candidate technologies for advanced lithography.

[12] Long (1999), pp. 26-28.

Lucent later decided to reduce its efforts in EUV lithography, and for a while the ATP considered the results of the project dormant, if not dead. Then, just recently, it was observed that some of the companies and staff members of the former ATP project had become involved in a new initiative centered on EUV lithography.[13]

Figure 6 - Model B: Small "Balanced" Company Awardee



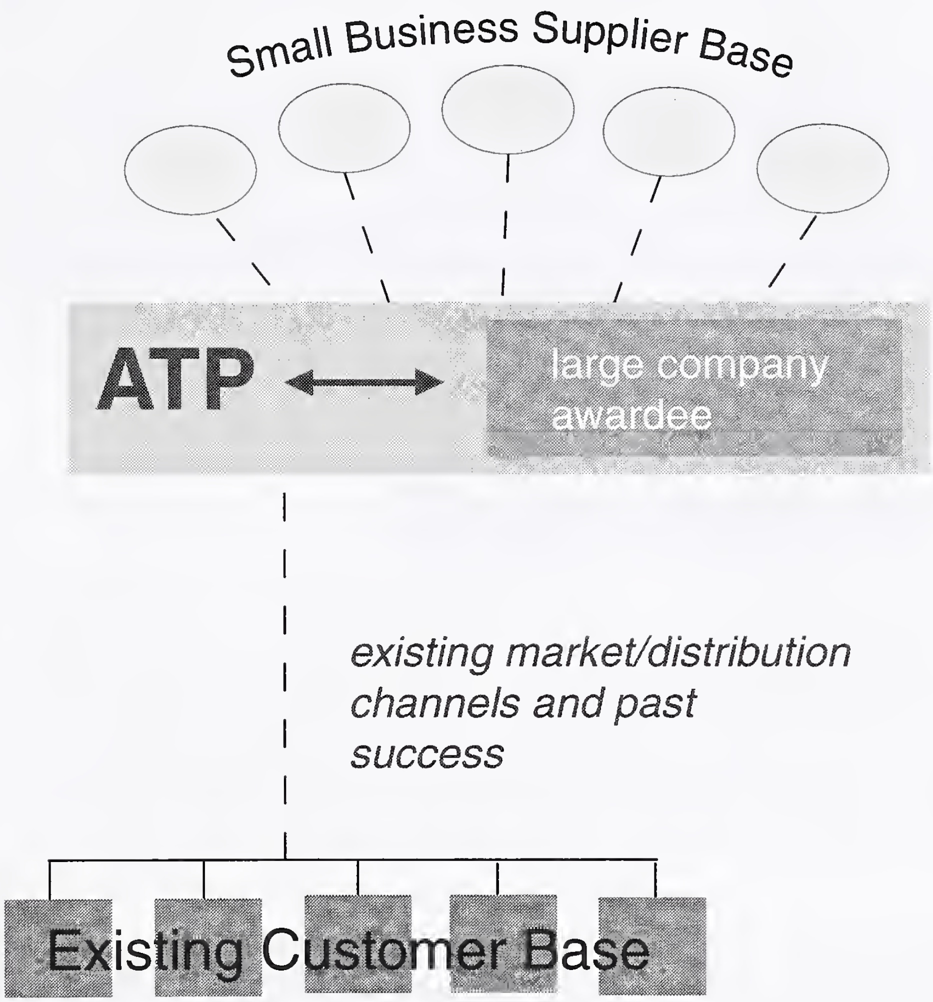
This example of "delayed" development illustrates the following points relevant to understanding the complexities of technology transfer: (1) The mobility of scientists and project administrators is an important route for technology transfer. (2) Companies that develop new technical capabilities often find ways to use them profitably while they are waiting for the originally intended use to develop. (3) The technology transfer path is often bumpy, with unexpected twists and turns. (4) And, in the words of the famous U.S. baseball player, Yogi Berra, "It's not over 'til it's over."

Model D in figure 8 is provided to show that all the alliances are not always in place prior to the award; but where they are not, the ATP looks for strong evidence that the market demand is there. Model D is for a small single-company awardee that combines strong university ties with strong business leadership and an "interested" market. This structure is well illustrated by ATP's award to Aastrom Biosciences, Inc., a company formed by several university medical researchers who wanted to move their ideas for human stem cell growth from the university laboratory into

[13] Long (1999), pp. 75-77.

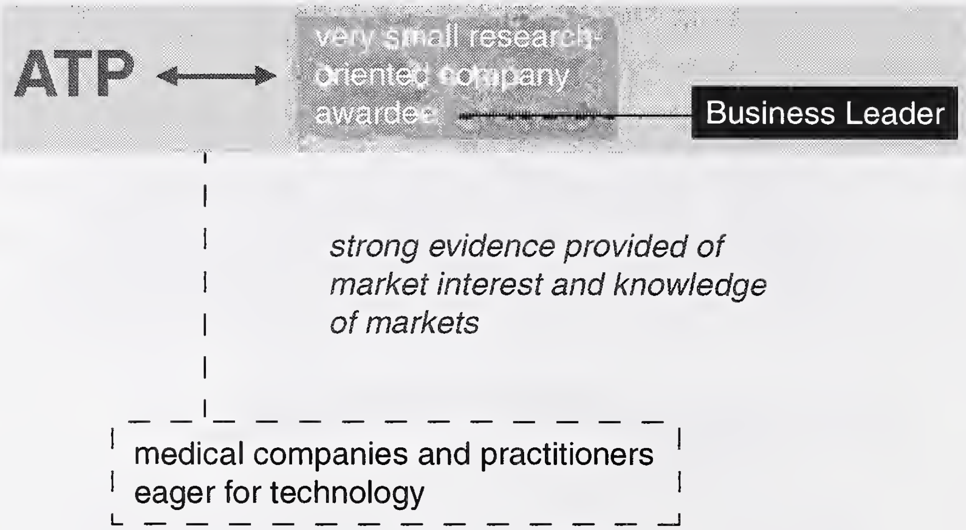
the commercial arena. The professors brought in an experienced business professional who demonstrated in-depth knowledge of the medical markets they would target. At the same time, they were able to support their argument that interest by the medical market in human cell growth was growing. As a result, the ATP saw viability in the proposal. Without evidence of market demand, such a proposal is generally considered in a "technology-push" situation. "Build it and they will come" arguments are not likely to fare well in ATP competitions for funding. In the case of the Aastrom proposal, the business case appeared viable, and by the end of the research project, Aastrom had become unusually successful in attracting partners and investment capital. Their system is nearing the end of clinical trials with breast cancer patients. Numerous technical papers have added knowledge spillovers to the large expected benefits to patients who will find it easier to undergo a bone marrow transplant.[14]

Figure 7 - Model C: Large Company Awardee Affiliated with Its Supplier Base



[14] RTI (1998).

Figure 8 - Model D: Small Research-Oriented Company Awardee with Strong Universities Ties, Strong Business Leader, and Demonstrated Market Interest



The models in figures 5 through 8 are not exhaustive of single-company ATP project structures. Other themes and variations could be illustrated. They would add to the mix by showing collaborations with Federal laboratories to extend research, with State government development offices to provide various kinds of assistance, and with other informal allies and subcontractors to better enable the applicant to meet the ATP's multiple criteria.

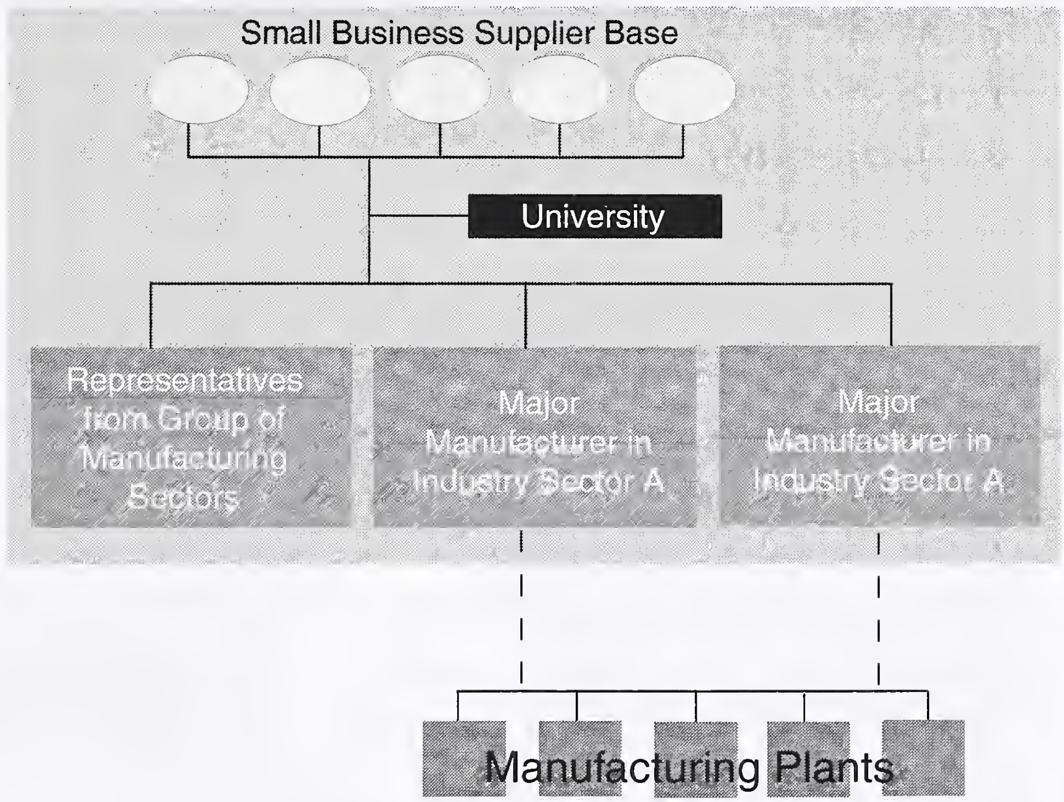
Looking now at the models of joint-venture projects shown in figures 9 through 11, we see in model E (figure 9) a vertically structured joint venture, with the ATP partnership broadly encompassing of project participants. This example is illustrative of ATP's project with the Automobile Body Consortium to develop technologies for dimensional control of assembled parts in discrete manufacturing.[15] The joint-venture membership extends across approximately eight members of the automotive supplier base, includes one university (and another in a subcontractor role), two major auto manufacturing companies, and a user group with members from other industry sectors. In this particular case, the joint-venture participants chose to direct the bulk of ATP funding to pay for the university research. The structure of this joint venture has proven highly successful in diffusing the technology within U.S. auto assembly plants. It has proven tougher to penetrate markets across industry lines, though steps in that direction are now being taken.

Model F in figure 10 shows a joint venture with researchers and test sites coordinated around a non-profit hub. This model is illustrative of an early funded ATP project to develop a fully integrated, standard-based, data-sharing framework for concurrent engineering of electrical products. A "missing commercialization component" is added in to highlight the importance of

[15] Long (1999), pp. 38-40.

evaluating each project's structure in terms of the goals. In the actual project there was no company among the joint venture members whose focus it was to commercialize the developed technology, and this omission appears to have impeded subsequent progress in diffusing the technology more broadly.[16]

Figure 9 - Model E: Joint-Venture Awardee, Vertically Structured



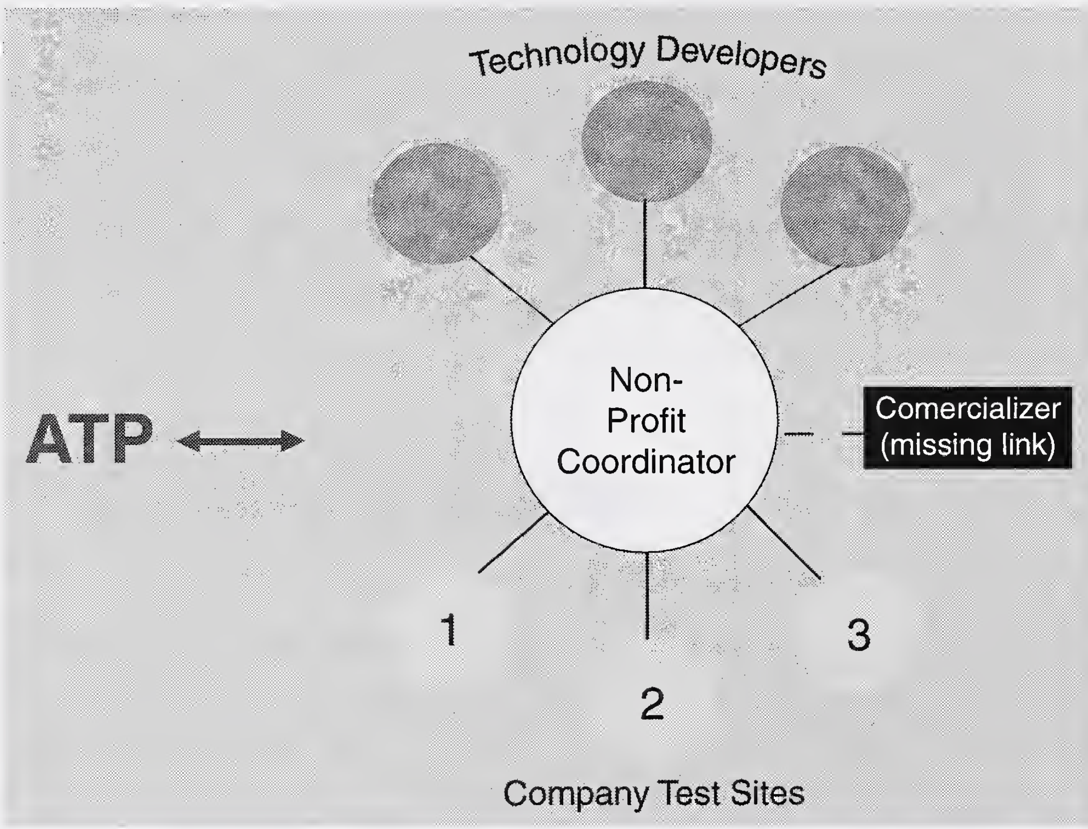
Model G in figure 11 shows a horizontally structured joint venture with competitors coordinated through a steering committee made up of various members. Although hybrid joint ventures that are vertically structured, with horizontal elements, are common, pure horizontal joint ventures among fierce competitors have been less common in the ATP. When they have occurred, they generally have been formed to address common infrastructual problems in the industry sector. If the participants are direct competitors, the challenge is to keep them focused on truly generic technology equally useful to the entire industry, and committed to transfer the results to the rest of the industry. An example of an ATP project that addressed common industry problems successfully with a considerable degree of sharing among collaborating participants is the Printed Wiring Board Joint Venture Project. In this horizontally structured joint venture, sharing among participants was made easier by the fact that each had a particular market focus and they

[16] Long (1999), pp. 44-45.

were actually not head-to-head rivals.[17] Another ATP horizontally structured joint venture that does have head-to-head rivals is currently under review. It appears to have difficulty in developing generic technologies equally useful to others in the industry and in freely sharing results.

The diversity of these models demonstrates that the ATP does not impose a proscriptive, one-size-fits-all, business model on participating companies. Rather, it sets out the performance requirements via its selection criteria and leaves it to each individual applicant to decide how it will choose to make its business case. The approach preserves the autonomy of companies to plan and structure their ATP projects with considerable flexibility, while also preserving ATP's ability to foster broader and more rapid technology diffusion.

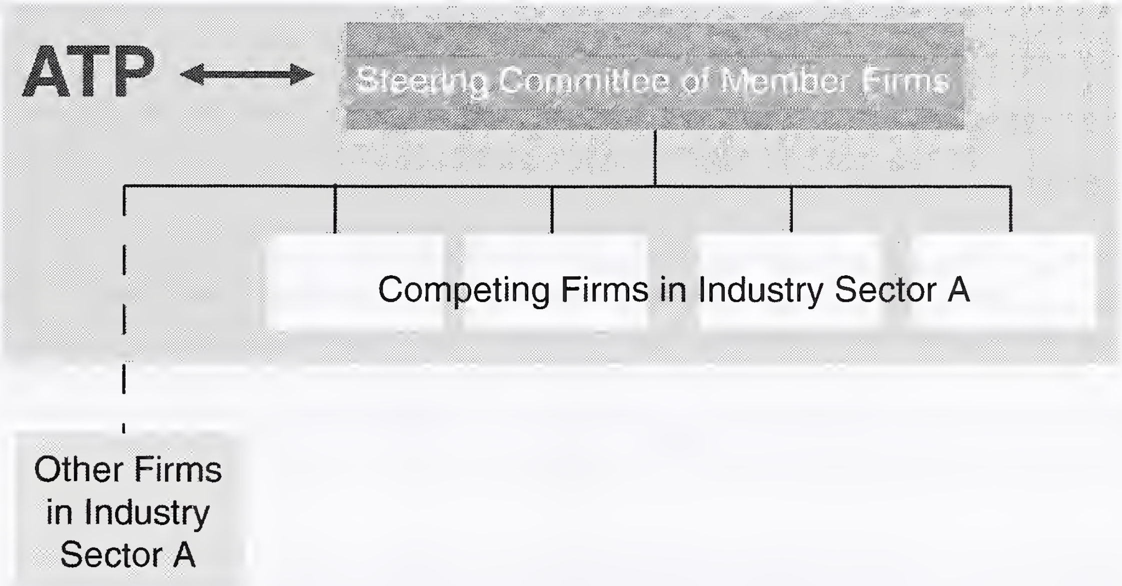
Figure 10 - Model F: Joint Venture, "Hub and Spokes" Structure



Research is currently being pursued by the ATP's Economic Assessment Office to examine features of these various arrangements that augment success. The effectiveness of collaborative relationships -- formal and informal -- is being examined in terms of achieving both technical and commercial goals.

[17] Link (1998), pp. 43-51.

Figure 11 - Model G: Joint Venture, Horizontal Structure



6. Achieving Intra-Firm, Intra-Team, Intra-Industry, and Inter-Industry Technology Diffusion

It is at the industry level and the economy-wide level that we usually think about technology diffusion, but it actually begins at the firm and collaborating team levels. That a technology will diffuse within the innovating firm may be problematic. For example, when an innovation occurs within the research laboratory of a large corporation, getting it adopted by a business unit may be as challenging as the task faced by a small firm attempting to gain acceptance of its products in the market. For this reason, the ATP holds large companies that have considerable strength in their marketing, production, and distribution departments to the same requirements as smaller companies to demonstrate integrated research and business plans. The ATP has also learned the critical importance of having commitment at the highest company levels to projects that it is funding in the research department of a large company. A hazard to projects funded without this commitment is that management may be more likely to shift its strategies in ways that effectively shut out the possibility of intra-firm adaption of the technology even if the research is successful. Insisting on integrated plans and high-level commitment does not eliminate these risks, but it is ATP's view, supported by experience, that it may reduce the likelihood of failure to follow through on the plan.

There is another interesting type of intra-firm effect that has been reported by ATP evaluators: a demonstration effect on project management outside the walls of the ATP project. In a study of the effect of ATP on company research cycle time, Laidlaw reported that 86% of the ATP-awardees surveyed experienced benefits beyond the walls of the project (1) by adapting specific "ATP practices" to related projects, (2) by applying methodologies and processes used or developed in the ATP project to the firm as a whole, (3) by adopting more widely an attitude developed in the ATP project in favor of speedier processes, and (4) by taking advantage of the positioning provided by the enabling technologies developed in the ATP project to accelerate the development of a whole series of related applications.[18] This represents a form of diffusion -- not of the specific technology per se -- but of attitudes, approaches, cultural effects, and precursor technologies developed in the project.

Analogous to the problem of intra-firm diffusion is diffusion of the technology among collaborating organizations. This requires not only an organizational structure that works, as was discussed in section 5, but it also requires that the team members be effective in working together and sharing results -- a challenge which is not always met in collaborative efforts. It is the ATP's experience that about 20% of projects that it announces for funding but which are never completed, are joint ventures that fall apart before they ever get started. The typical problem is that members cannot reach agreement over the terms of the collaborative relationship, the sharing of intellectual property, and other issues.[19] Yet many collaborative relationships work smoothly and with good results. By collaborating, companies may gain new technical capabilities, access to specialized assets, funding, new suppliers and customers, and other advantages, or they may internalize spillover effects from developing new infrastructure technology for which they share a common need.[20]

It has been the ATP's experience that achieving inter-industry diffusion of technology in most industry sectors is much more difficult that intra-industry diffusion, even though many of the technologies funded by the ATP have a strong potential for multiple uses. The presence of suppliers of the technology with customers in multiple industry sectors is an example of a factor that helps in crossing industry lines. For example, an ATP-funded technology that was quickly applied across industry lines was the computer visualization and computational dynamics technology developed by Engineering Animation, Inc. The company has applied the technology in applications ranging from medical uses to entertainment. Among the many factors that appear to present obstacles to moving technology across industry lines are the following: (1) substantial and costly adaptation required for the new sector uses; (2) specialized assets and know-how needed to accomplish adaptation; (3) the requirement that customers substantially change their behavior to use the new technology; (4) suppliers "stove-piped" in the originally innovating industry sector; and (5) low exposure of suppliers in the new industry sector to the new technology. In most cases, inter-industry technology diffusion will be a lengthy process.

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[18] Laidlaw (1997), pp. 34-37.

[19] The ATP is working to further identify and address these issues, and to call them to the attention of would-be collaborators early in their efforts to form joint ventures.

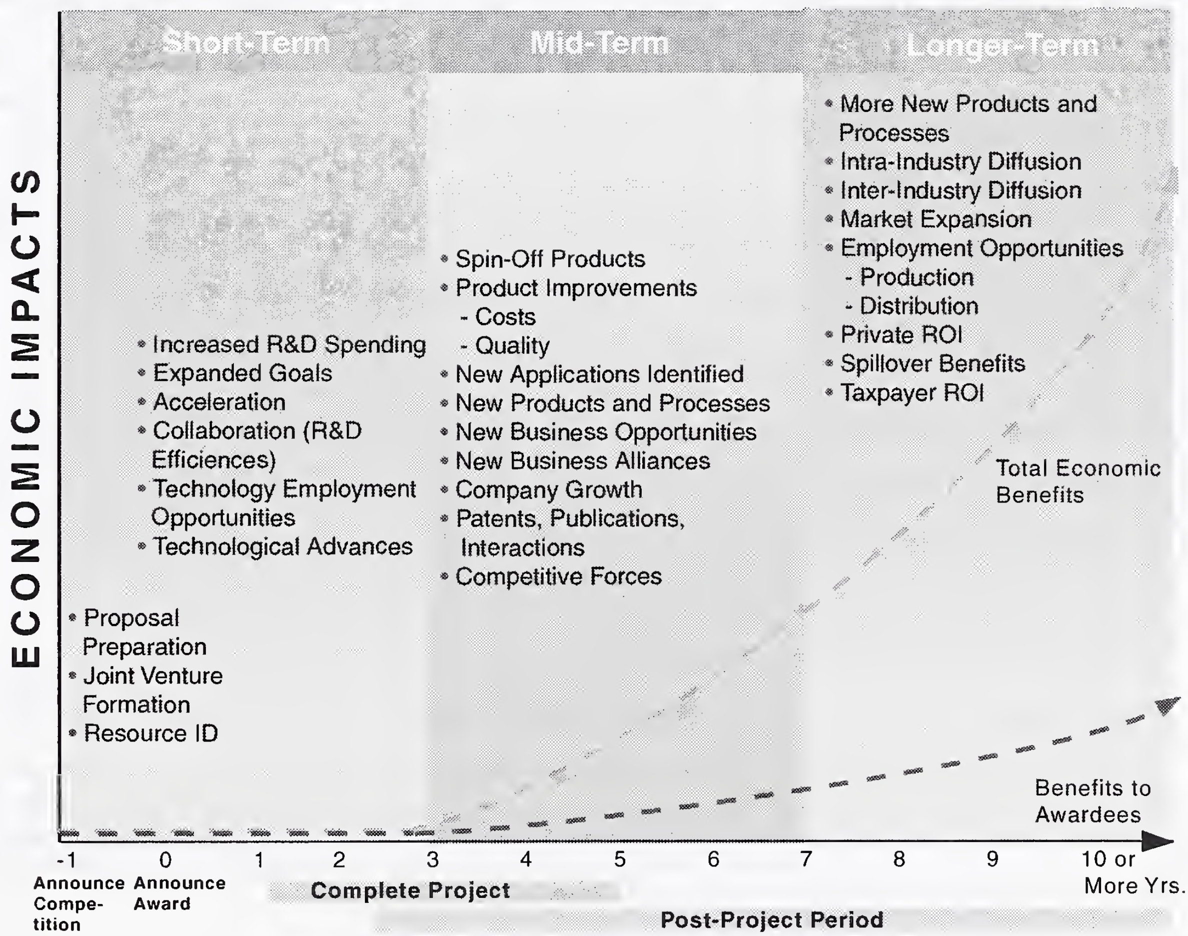
[20] Several ATP studies have analyzed and reported on ATP collaborations. See, for example, Vonortas (1999) for a comparison of ATP joint ventures with research joint ventures formed outside of the ATP; Powell (1997 and 1999) for measures of ATP collaborative activities; and Silber (1996) for survey results on collaborative activity in ATP projects. A study underway by Professors Jeffrey Dyer of Brigham Young University and Benjamin Powell of the Wharton School, University of Pennsylvania, is investigating the determinants of success in government-sponsored R&D consortia for the ATP. This study promises to make a valuable contribution to the understanding of the growing role of collaboration in international competition. For more on collaborations, see also Ouchi (1989) and Dyer (1999).

The ATP is looking more closely at ways to increase the likelihood that the multi-application potential of the technologies it funds will be realized as quickly as possible. It is not enough to accept the assertion of applicants that the potential is there. If the potential is to be realized, it is important to learn more about the obstacles to cross-industry diffusion of technologies and the project structures that will work best, and to bring that knowledge into the selection process.

7. Time Path for Technology Diffusion

Figure 12 shows conceptually how the time path of a successful project might unfold, starting with the announcement of a competition by the ATP. On this conceptual chart, economic impacts are depicted on the vertical scale, and time on the horizontal scale. The lower of the two curves, rising from left to right, shows returns to the project innovators increasing over time as they commercialize their technology. The upper curve shows returns to the economy at large increasing as the technology diffuses into wider use. The difference between the two curves reflects benefits that "spill over" to those outside the project.

Figure 12 - Conceptual Time Path for ATP's Technology Diffusion and Expected Impacts



The chart in figure 12 is annotated with events that may lead, or contribute, to the generation of economic benefits during three time periods designated by the shading. Upon announcement of a competition by the ATP, companies begin to prepare their proposal, form collaborative relationships, and identify resources. If they receive an ATP award, they tend to increase their own R&D spending, expand their goals, accelerate research, hire scientists and engineers, and make technical progress.[21] Even under the most favorable of conditions, it takes time for new technologies to be developed, time for them to be commercialized, and still more time for commercial volume to increase, for multiple applications to be implemented, and for spillover effects to manifest broadly. The actual dates on the time line will vary considerably by technology area and other factors. Few, if any, of ATP's projects are yet old enough to allow adequate time for truly broad diffusion, though substantial evidence of early diffusion can be found. For a comparison of two ATP projects, one that developed a new medical technology and the other a new software technology, we found that more than a decade had elapsed before the medical technology reached the point of regulatory approval needed to begin sales of the system to clinics. Only three to four years were necessary for software products based on the computing technology to be licensed for use.[22]

8. Early Results[23]

Thus far, the ATP has some successes and some failures. Overall, the benefits from only a few successes appear to dwarf the total costs of the program.[24]

Of the first 38 completed ATP projects, whose assessment was reported on in early 1999, seven had produced technologies that were continuing to make particularly robust progress in the post-project period in terms of commercializing and diffusing the technologies. Another 16 technologies were showing continuing progress, but it was too early to reach conclusions about ultimate adoption. Five of the original innovating companies were in bankruptcy and their technologies appeared for the most part dormant. The others did not appear totally dormant, but were not showing much activity.

During the same time period that the first 38 ATP-funded research projects were completed, 24 additional projects that were originally scheduled to complete during the period were stopped. A third of them were stopped at the company's request due to changes in their strategic goals, the loss of key members, or a negative change in the market. Twenty-one percent were stopped due to financial distress of the companies. Another 21% were stopped due to lack of satisfactory

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[21] For statistical results for these effects, see Powell (1997).

[22] These two illustrative project time lines are shown in Long (1999); he also references the conceptual time line developed by Ruegg and shown here in figure 12.

[23] The ATP's Economic Assessment Office evaluates progress of the program towards meeting its goals. Through its own staff and outside academic and consulting economists it has conducted a number of assessment studies. These can be found at the ATP's website (www.atp.nist.gov/eao/eao_pubs.htm). An overview of the ATP's evaluation plan and progress in implementation is provided by Ruegg (1998).

[24] See Long (1999), Ehlen (1999), RTI (1998), Link (1997), and Consad (1997).

technical progress. And, another 21% were the group of joint ventures mentioned earlier that never got started. Four percent of the not-completed projects were stopped early because they achieved earlier-than-expected technical success.

With the 1999 awards, the ATP has more than 400 additional projects either recently completed or in the pipeline. It should be expected that some of these will also succeed, some will fail, and many will return enough to cover their costs but will not be outstanding successes. It is important to understand that technical failure must be tolerated in a program that funds high-risk research; and, it is equally important to understand that there is no escape from instances of business failure, or mediocre performance, in the marketplace. It should be expected that relatively few ATP projects are likely to account for the largest share of program benefits.

To assess the performance of a program such as the ATP, it is essential to take a portfolio approach, not equating individual project failure with overall program failure. As long as the net benefits of the program's portfolio of projects over the long run are large; as long as the spillover benefits from the portfolio are also large; and as long as a substantial share of the net benefits and spillover effects are directly attributable to the ATP, the program is successfully fulfilling its mission.

9. *Conclusions*

The ATP takes the position that through deliberate and well conceived strategies for influencing technology development and diffusion, it can exert a positive impact on the national economy by increasing, accelerating, and broadening the use of the enabling technologies it funds. Its emphasis on business and economic issues, in addition to highly innovative technical ideas, sets it apart from most other government technology programs in the United States. That the ATP is influencing the planning and structuring of the projects it funds is evident in the proposals received and funded. Yet, the great variations among the plans and project structures that can be observed suggests that the ATP is not exerting an overly heavy hand, but rather is leaving substantial room for businesses to choose collaborative and business approaches that work best for them. Analysis of project outcomes and the alternative project structures employed offers an opportunity to assess which are more or less effective for different industry sectors and market conditions. For example, the challenges faced by certain projects in attempting inter-industry transfer of their technologies appear attributable at least in part to deficiencies in their original project structures. Formal and informal collaborative arrangements provide a means for companies of all sizes to strengthen both their research capabilities and their business cases. Of completed projects, some are showing robust progress towards commercialization and knowledge dissemination. Some appear dormant or nearly so. Most are somewhere in the middle. On net, the program appears to be succeeding. In addition, the ATP is providing a rich and valuable laboratory for learning more about the multiple dimensions of how public-private partnerships can and should function and how diffusion of technologies can be deliberately accelerated and broadened. For policy makers looking for ways to foster industry partnerships that stimulate technology transfer while maintaining a relatively low profile for the government, the ATP has a lot to offer.

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About the Advanced Technology Program

The Advanced Technology Program (ATP) is a partnership between government and private industry to conduct high-risk research to develop enabling technologies that promise significant commercial payoffs and widespread benefits for the economy. The ATP provides a mechanism for industry to extend its technological reach and push the envelope beyond what it otherwise would attempt.

Promising future technologies are the domain of the ATP:

- Enabling technologies that are essential to the development of future new and substantially improved projects, processes, and services across diverse application areas;
- Technologies for which there are challenging technical issues standing in the way of success;
- Technologies whose development often involves complex "systems" problems requiring a collaborative effort by multiple organizations;
- Technologies which will go undeveloped and/or proceed too slowly to be competitive in global markets without the ATP.

The ATP funds technical research, but it does not fund product development. That is the domain of the company partners. The ATP is industry driven, and that keeps it grounded in real-world needs. For-profit companies conceive, propose, co-fund, and execute all of the projects cost-shared by the ATP.

Smaller companies working on single-firm projects pay a minimum of all the indirect costs associated with the project. Large, "Fortune-500" companies participating as a single firm pay at least 60 percent of total project costs. Joint ventures pay at least half of total project costs. Single-firm projects can last up to three years; joint ventures can last as long as five years. Companies of all sizes participate in ATP-funded projects. To date, more than half of the ATP awards have gone to individual small businesses or to joint ventures led by a small business.

Each project has specific goals, funding allocations, and completion dates established at the outset. Projects are monitored and can be terminated for cause before completion. All projects are selected in rigorous competitions which use peer-review to identify those that score highest against technical and economic criteria.

Contact the ATP for more information:

- On the World Wide Web: http://www.atp.nist.gov;;
- By e-mail: atp@nist.gov;
- By phone: 1-800-ATP-FUND (1-800-287-3863);
- By writing: Advanced Technology Program, National Institute of Standards and Technology, 100 Bureau Drive, Stop 4701, Gaithersburg, MD 20899-4701.

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